# A New Innovation in Data Compression

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1. Introduction

# Historical Background

- JPL's primary concern is deep space exploration.
- Communicating with deep space probes presents a significant challenge.
- Data compression helps to meet this challenge by reducing the amount of data to transmit (or increasing the amount of science data returned).

# Historical Background

## The Challenge of Deep Space Communications

- **Communications performance decreases as the square of distance**
  - **Mars-Earth distance can reach over 400 *million* km**
  - **Typical GEO Earth communications satellite is only about 40 *thousand* km away**
  - **Communication is about 100,000,000 times harder from Mars!**
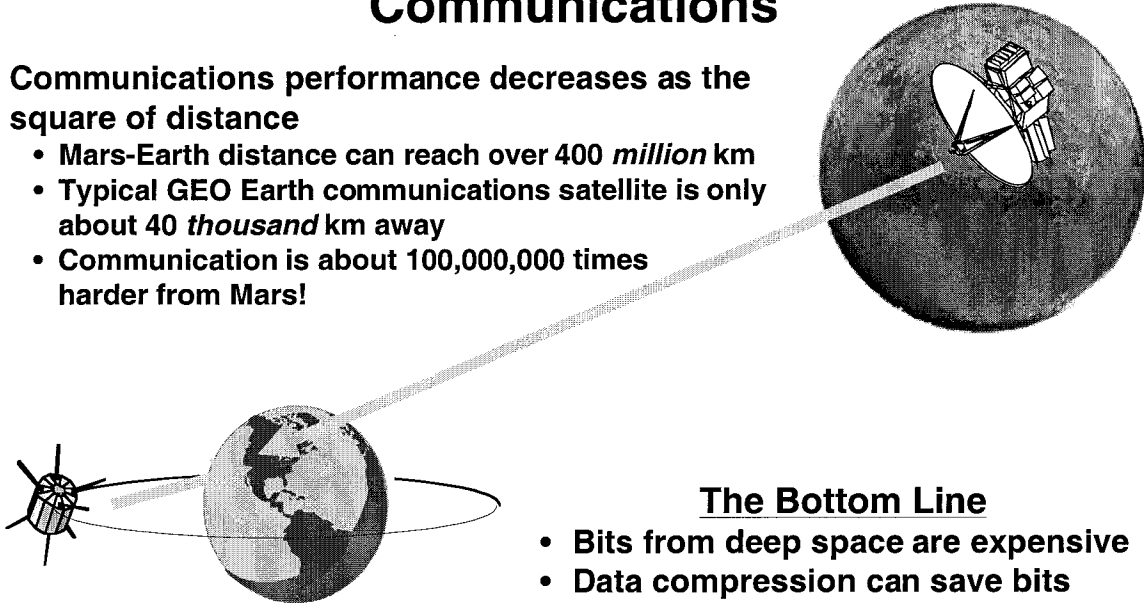
### The Bottom Line
- **Bits from deep space are expensive**
- **Data compression can save bits**

# Historical Background

## Why not use Commercial Off-The-Shelf Data Compression?

- Complexity
- Error containment
- Overall system considerations
- User needs are different
  - Different data types
  - No universal algorithm
- The benefits of data compression can be enormous when measured in terms of the equivalent transmitter power savings.
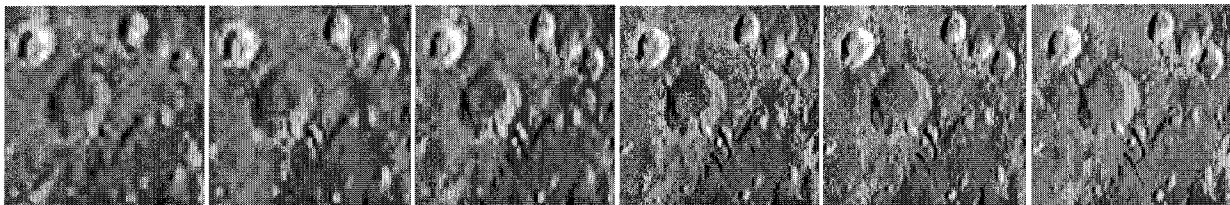
JPL compression research focuses particularly on image compression, because images tend to occupy the largest fraction of science data.

# Progressive Transmission of Compressed Image Data

Original Image:
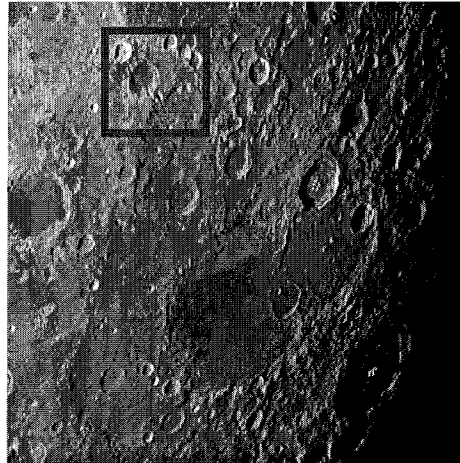
Progressive transmission (detail):

16.5 dB savings    15.5 dB savings    13.9 dB savings    9.0 dB savings    6.0 dB savings    2.3 dB savings*
(*lossless compression)

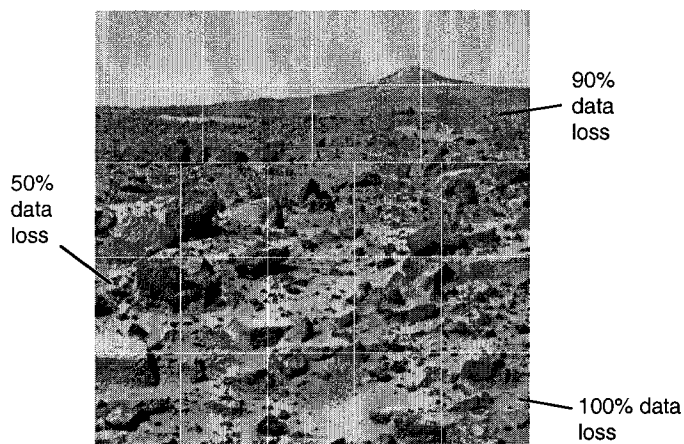# Error Containment in Progressive Wavelet Image Compression

The ICER progressive wavelet compression algorithm incorporates a novel error containment method integrated with packetization.

- Eliminates blockiness associated with conventional error containment techniques
- Arbitrary number of segments can be used to accommodate different channel error probabilities
- Supports standard CCSDS packets

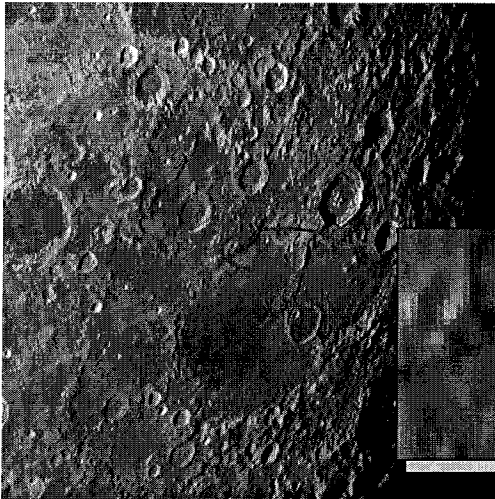This example simulates three channel errors during transmission of an image divided into 23 segments

90% data loss

50% data loss

100% data loss
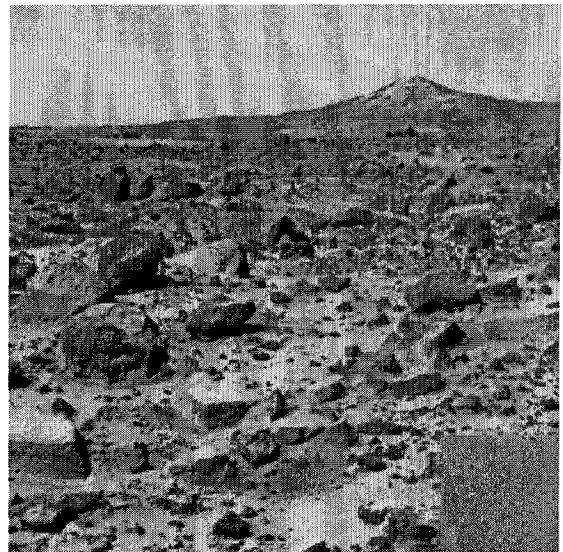
2 bit/pixel image after suffering three CCSDS frame losses due to channel errors

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# Error Containment in Progressive Wavelet Image Compression

Segmentation for error containment implemented *after* wavelet transform eliminates blockiness associated with the more conventional approach.
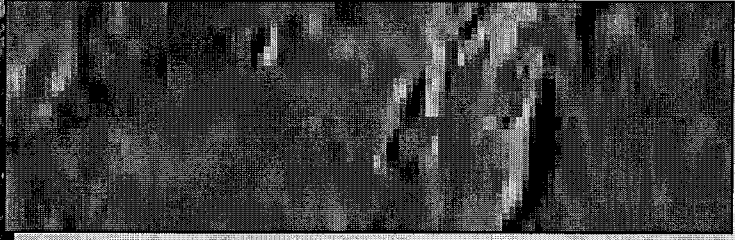
edge artifact from conventional technique

artifact eliminated with new technique

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# Progressive Compression of 3D Object Models

# New Entropy Coding Technique

## Background

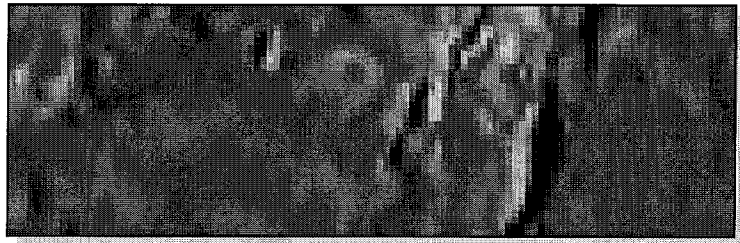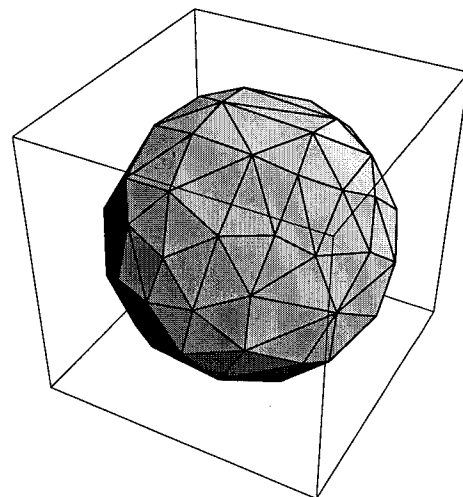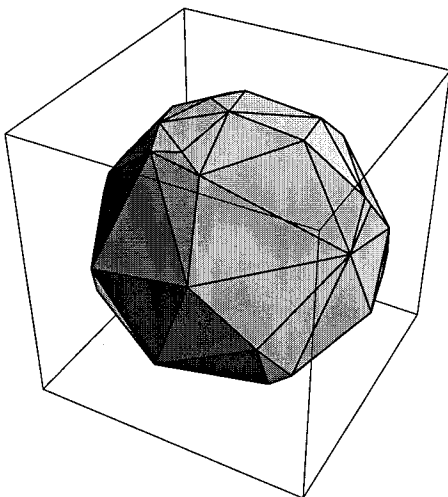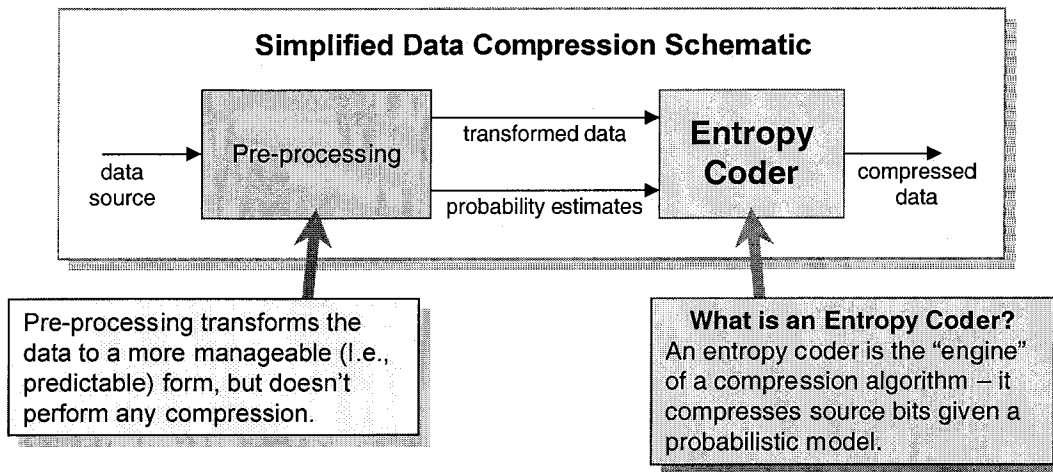An **entropy coder** is an important component in compression algorithms.



**Simplified Data Compression Schematic**

Pre-processing transforms the data to a more manageable (I.e., predictable) form, but doesn't perform any compression.

What is an Entropy Coder? An entropy coder is the "engine" of a compression algorithm – it compresses source bits given a probabilistic model.

* *Pre-processing* produces transformed data and associated probability estimates
* *Entropy coding* compresses the transformed data based on the probability estimates

## 1. Introduction

# Historical Background

- More accurate probability estimates yield better compression.
- The best type of binary entropy coder is one that is **bitwise adaptive** (allows more effective compression).
- The traditional bitwise adaptive method of entropy coding is **arithmetic coding**; however, arithmetic coding has high complexity
  - Arithmetic coding is used, for example, in the new JPEG 2000 image compression standard.

# New Entropy Coding Technique

**Why the new entropy coding technique is significant:**

- **Encoder is** *adaptable*
  - **Probability model can be updated with each source bit – allows sophisticated source models for better compression**
  - **Same functionality as arithmetic coding, the current state-of-the-art adaptable entropy coding method**



- **Entropy coder is** *general purpose* **– can be used in a variety of compression applications**
- *Excellent performance* **– within 1% of theoretical limit in typical applications**
- *Design Flexibility* **– Performance can be traded for complexity**
- **Low complexity (fast) encoding and decoding**
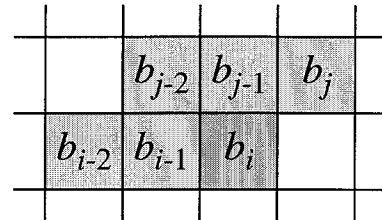
> "... a clever new approach... The method is quite intriguing in its novelty relative to previous methods."
>
> – anonymous reviewer for 2001 IEEE Data Compression Conference

2. Technology Description

# The Technology

- New method of entropy coding - **recursive interleaved entropy coding**.
- A module for use in various data/image compression algorithms.
- Converts a sequence of bits with probability estimates to a sequence of compressed bits.
- Our new method has speed advantages over the competing method, arithmetic coding.

# R & D Status

- Development stage
  - Prototype software has been used to evaluate speed and compression effectiveness.
  - Coder has been successfully implemented in two image compression algorithms (performing lossless and lossy compression).
- Development hurdles
  - Achieved:
    - Current implementation is reasonably fast.
    - A **coder design** procedure has been demonstrated.
  - Remaining:
    - Investigate further speed improvements.
    - Find a coder design procedure or coder designs that offer optimized performance.

# Tech Details

- Method is based on recursive interleaving of variable-to-variable length binary codes.

- Basic idea: encoder formats compressed binary data in such a way that the decoder receives the bits it needs at the point that it needs them – **decoder synchronized encoding**

# What's New?

- Compared to arithmetic coding: functionality is the same, but the new method is faster.
  - Note that arithmetic coding was introduced more than 20 years ago, and considerable research effort has been invested in complexity reductions
- Compared to non-recursive interleaved entropy coding, functionality is the same but with the new method it is easier to make the compression effectiveness close to the theoretical limits.
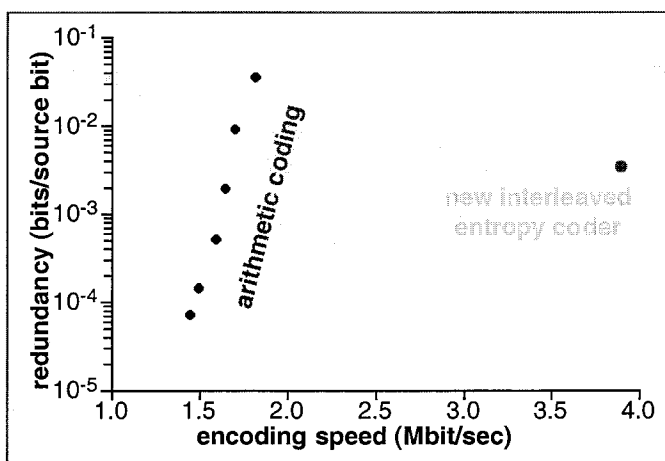
# Technical Advantages

**Speed advantage:**

- **Encoding is *twice as fast* as arithmetic coding at similar amounts of redundancy.**
- **Decoding is about 50% faster than arithmetic coding.**
- **Other coder designs are possible for different speed/performance tradeoffs.**

*Arithmetic coding is the current state-of-the-art technique for adaptable entropy coding.*

**Timing tests used:**
- **Sun Ultra Enterprise with a 167 MHz UltraSPARC processor**
- **binary source with uniformly distributed probability-of-zero**
- **"shift/add" arithmetic coder from [1]. This is widely used in the literature because it is fast and the source code is publicly available.**

Reference:
[1] A. Moffat, R. M. Neal, and I. H. Witten, *ACM Trans. Inf. Sys.*, vol. 16, no. 3, pp. 256--294, July, 1998.

# NASA Relevance

- NASA deep space application: primarily for image compression
- Benefit to NASA: increased compression, resulting in spacecraft power savings or increased science data returned
- Other applications: compression of other data types (e.g., hyperspectral), image archival, etc.

# NASA Plans/Options

- Internal development:
  - Investigate two potential improvements
  - Integrate into deep space data compression applications

# Remaining R&D

- The compression technique has already been successfully demonstrated and is ready to be integrated into data compression applications.
- The technology is very new, so further research and development may lead to additional improvements in encoding and decoding speed and/or reductions in memory used in the encoder.
- Outside expertise in medical imaging would be needed to integrate the technology into an existing system (or develop a new system).

5. Commercial Applications

# Applications Identified

- The new compression innovation is a general purpose module that could be used as part of numerous data compression applications.
- Applications include:
  - Data archival and retrieval systems (e.g., for medical imaging)
  - Efficient data transmission systems
  - Broadcast
  - Internet
  - Mobile Computing

# Intellectual Property

- Proprietary technologies include the new encoding and decoding methods, as well as innovations used to reduce encoder memory use.
- Provisional patent applications have been filed for these innovations
- Public disclosure:
  - A. Kiely and M. Klimesh, "An Adaptable Binary Entropy Coder," Proceedings 2001 IEEE Data Compression Conference, March 27–29, pp. 391-400.

7. Moving Forward

# Next Step

- To discuss license or partnering possibilities, contact:

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